

STRUCTURE AND MANUFACTURING METHOD FOR NITRIDE-BASED LIGHT-EMITTING DIODES

FIELD OF THE INVENTION

[0001] The present invention relates to a structure and a manufacturing method for light-emitting diodes and, more particularly, to a structure and manufacturing method for GaN-based light-emitting diodes, or light-emitting diodes made of other material with wide band gap.

BACKGROUND OF THE INVENTION

[0002] As shown in Figure 1, the structure of a conventional GaN-based light-emitting diode includes a substrate 1, a buffer layer 2 grown on substrate 1, an n-type GaN layer 3 grown on buffer layer 2, a light-emitting layer 4 grown on n-type GaN layer 3, and a p-type GaN layer 5 grown on light-emitting layer 4. The light-emitting diode is manufactured with the following steps:

[0003] (1) Using the inductively coupled plasma-reactive ion etching (ICP-RIE) dry etching method to etch downward through p-type GaN layer 5, light-emitting layer 4, and reach n-type GaN layer 3 in order to form an n-metal forming area 6 of about 1 μm deep, as shown in Figure 2A;

[0004] (2) Forming a transparent and conductive first ohmic contact electrode 7 on p-type GaN layer 5, as shown in Figure 2B;

[0005] (3) Forming a second ohmic contact electrode 8 on n-metal forming area 6, as shown in Figure 2C; and

[0006] (4) Forming pads 9 on both first ohmic contact electrode 7 and second ohmic contact electrode 8, as shown in Figure 2D.

[0007] Thus, a conventional GaN-based light-emitting diode is manufactured.

[0008] In the aforementioned conventional method, a transparent conductive layer 7 is made of Ni/Au, which has a low optical transmittancy. Therefore, the external quantum efficiency of the manufactured light-emitting diodes is poor.

SUMMARY OF THE INVENTION

[0009] The present invention is to provide a structure and manufacturing method for reducing the contact impedance of the ohmic contacts of the GaN-based light-emitting diodes with a digital penetration layer and an Indium Tin Oxide (ITO) layer. To achieve this, the present invention utilizes the ITO layer on the digital penetration layer to form a low-impedance, transparent, and conductive ohmic contact layer. Because the ITO has a high optical transmittancy (>90%), the external quantum efficiency can be greatly improved. The n-metal forming area is formed on the light-emitting layer to reduce the operating voltage. Furthermore, the structure of the present invention having a p/n-metal pitch, which is about 0.2 μ m, is good for flip-chip packaging and improving the external quantum efficiency.

[0010] These and other objects, features and advantages of the invention will be apparent to those skilled in the art, from a reading of the following brief description of the drawings, the detailed description of the preferred embodiment, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 shows a cross-sectional view of the structure of a conventional GaN-based light-emitting diode.

[0012] Figures 2A-2D show the manufacturing steps of a conventional GaN-based light-emitting diode of Figure 1.

[0013] Figure 3 shows a first preferred embodiment of the present invention.

[0014] Figure 4 shows a cross-sectional view of the digital penetration layer of the present invention.

[0015] Figures 5A-5D show the manufacturing method for the first preferred embodiment of the present invention of a GaN-based light-emitting diode.

[0016] Figures 6A-6D show the manufacturing method for the second preferred embodiment of the present invention of a GaN-based light-emitting diode.

[0017] Figure 7 shows a TEM image of the n-metal forming area on top of the light-emitting layer.

[0018] Figure 8 shows the current-voltage relationship diagram of a conventional light-emitting diode and the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[First Embodiment]

[0019] As shown in Figure 3, a substrate 10 is provided, and a buffer layer 20 is formed on substrate 10 using metal organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), or liquid phase epitaxy (LPE). The present invention uses the MOCVD method. The same MOCVD method is used to form an n-type GaN layer 30 on top of buffer layer 20, an light-emitting layer 40 on top of n-type GaN layer 30, a p-type GaN layer 50 on top of light-emitting layer 40, and a digital penetration layer 100 on top of p-type GaN layer 50. Figure 4 shows the cross-sectional view of digital penetration layer 100. Digital penetration layer 100 is made of $\text{Al}_x\text{In}_y\text{Ga}_{1-x-y}\text{N}_z\text{P}_{1-z}$ and $\text{Al}_p\text{In}_q\text{Ga}_{1-p-q}\text{N}_r\text{P}_{1-r}$ with increasing (10Å-90Å) and decreasing (90Å-10Å) thickness, respectively, where $0 < x, y, z, p, q, r < 1$. When the light-emitting layer emits light with wavelength between 380nm and 560nm, the optical transmittancy of the digital penetration layer is greater than 80%.

[0020] A single etching step of a multi-step dry etching method is used to etch digital penetration layer 100, p-type GaN layer 50, and light-emitting layer 40. The etching terminates at light-emitting layer 40. At the end of the etching, an n-metal forming area 60 is formed. The present invention uses a dry etching method of ICP-RIE, as shown in Figure 5A.

[0021] An ITO layer 110 is formed on top of digital penetration layer 100 using e-gun vaporation, sputtering, or thermal-resistance evaporation. The present invention uses sputtering deposition. As shown in Figure 5B, ITO layer 110 formed with the sputtering deposition method can have the thickness of 100Å-20000Å, while the preferred thickness of the present invention is 1000Å-4000Å.

[0022] ITO layer 110 formed on top of digital penetration layer 100 is used as the first ohmic contact electrode because it is a p-type ohmic contact and with high optical transmittancy to improve the external quantum efficiency. An n-type ohmic contact layer is formed with the one of the aforementioned methods in the n-metal forming area 60 to be used as a second ohmic contact electrode 80. Because the ICP-RIE etching terminates at the light-emitting layer, there will be imperfection, which absorbs the free carriers and reduce the equivalent surface density. In addition, due to the surface vacant area, there is no carrier between the p/n junction area in spite of the existence of InGaN tunnel. On the other hand, n-metal forming area 60 is electroplated with a layer of Ti/Al. Because InGaN forms with Ti/Al an ohmic contact, which has a lower ohmic contact impedance than that of an ohmic contact formed by N-GaN with Ti/Al, a low-impedance ohmic contact is formed with the aid of the aforementioned imperfection. Also, because the dry etching does not etch as deep as conventional GaN-based light-emitting diodes, the lateral impedance is smaller and the operating voltage can be reduced.

[0023] The present invention uses e-gun evaporation deposition to form n-type ohmic contact layer 80, with the material of Ti, Al, Au, Ni, In, Sn, Zn, Cr, Cu, W, Pt, Pd, ITO, Indium Oxide, Tin Oxide, or Aluminum Zinc Oxide, as shown in Figure 5C.

[0024] Finally, contact pads 90 are formed on ITO layer 110 and second ohmic contact electrode 80 using one of the aforementioned methods. The present invention uses e-gun evaporation deposition. Contact pads 90 are made of Ti, Al, Au, Cr, Ni, Pt, or their combination, as shown in Figure 5D.

[0025] Figure 7 shows the TEM image of n-metal forming area 60 formed on light-emitting layer 40 with a dry etching method.

[0026] Figure 8 shows the current-voltage relationship diagram of a conventional GaN-based light-emitting diode and the present invention. With a 100% test on the 2"-diameter wafers manufactured with a conventional method and the present invention, the former shows an average forward bias of 3.17V and yield rate is 97.95% when the input current is 20mA, while the latter shows an average forward bias of 3.12V and yield rate is 98.17%. The former has the yield rate of 87.68% when the leakage current is less than 1mA at -5V, while the latter has the yield rate of 92.81%. The results show that the present invention has superior electrical characteristics to a conventional GaN-based light-emitting diode.

[Second Embodiment]

[0027] As shown in Figure 6A, a substrate 10 is provided, and a buffer layer 20 is formed on substrate 10 using metal organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), or liquid phase epitaxy (LPE). The present invention uses the MOCVD method. The same MOCVD method is used to form an n-type GaN layer 30 on top of buffer layer 20, an light-emitting layer 40 on top of n-type GaN

layer 30, a p-type GaN layer 50 on top of light-emitting layer 40, and a digital penetration layer 100 on top of p-type GaN layer 50.

[0028] A two-step dry etching method of a multi-step dry etching method is then used to etch downward. The first step etching etches downward digital penetration layer 100, p-type GaN layer 50, and light-emitting layer 40. The etching terminates at light-emitting layer 40. At the end of the etching, an n-metal forming area 60 is formed. The second step etching etches downward part of n-metal forming area 60, light-emitting layer 40, and n-type GaN layer 30 to form a trench 61. The present invention uses a dry etching method of ICP-RIE. An ITO layer 110 is formed on top of digital penetration layer 100 using e-gun vaporation, sputtering, or thermal-resistance evaporation. ITO layer 110 formed on top of digital penetration layer 100 is used as the first ohmic contact electrode because it is a p-type ohmic contact and with high optical transmittancy. The present invention uses sputtering deposition. As shown in figure 6B, ITO layer 110 formed with the sputtering deposition method can have the thickness of 100Å-20000Å, while the preferred thickness of the present invention is 1000Å-4000Å.

[0029] An n-type ohmic contact layer is formed with the one of the aforementioned methods in the n-metal forming area 60 to be used as a second ohmic contact electrode 80. The present invention uses e-gun evaporation deposition to form n-type ohmic contact layer 80, with the material of Ti, Al, Au, Ni, In, Sn, Zn, Cr, Cu, W, Pt, Pd, ITO, Indium Oxide, Tin Oxide, or Aluminum Zinc Oxide, as shown in Figure 6C.

[0030] Finally, contact pads 90 are formed on ITO layer 110 and second ohmic contact electrode 80 using one of the aforementioned methods. The present invention

uses e-gun evaporation deposition. Contact pads 90 are made of Ti, Al, Au, Cr, Ni, Pt, or their combination, as shown in Figure 6D.

[0031] While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but, on the contrary, it should be clear to those skilled in the art that the description of the embodiment is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.